Preparations for the Insertion of “Long-Bo” in the Liquid Argon Purity Demonstrator

Fermilab

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Introduction

The liquid argon purity demonstrator (LAPD) is currently moving into phase two of its operation—the insertion of a time projection chamber (nicknamed “Long-Bo”). A Time Projection Chamber (TPC) placed in liquid argon (LAr) can be used to detect and measure charged particles. Scintillation counters placed uniformly around the LAPD tank will act as a trigger to tell the TPC to begin recording data. When a charged particle, such as a cosmic ray muon, passes through one scintillator, it opens a 50 ns window. If this muon passes through a second scintillator placed directly across from the other, the signal from the second scintillator will create a coincidence with the first. The coincidence is then recorded and triggers the TPC. The scintillation counters not only ensure that the TPC is recording when it needs to, but also provide a count of how many particles are observed.

When a charged particle passes through liquid argon it leaves behind a trail of ionized electrons. These electrons, in the presence of an electric field inside the TPC, will drift uniformly upward to a plane of wires. These wires then can be used to recreate a 3D image of the muon path by measuring the drift time and position of the electrons, thus creating images similar to those seen in a bubble chamber.

The purpose of the LAPD is to provide initial research for the Long Baseline Neutrino Experiment (LBNE). The LBNE will use liquid argon to detect neutrino interactions. Neutrinos rarely interact with matter, so it is important to have a large detector. The LAPD will be able to show that sufficient purity levels in liquid argon can be reached to allow electrons to drift a large distance.

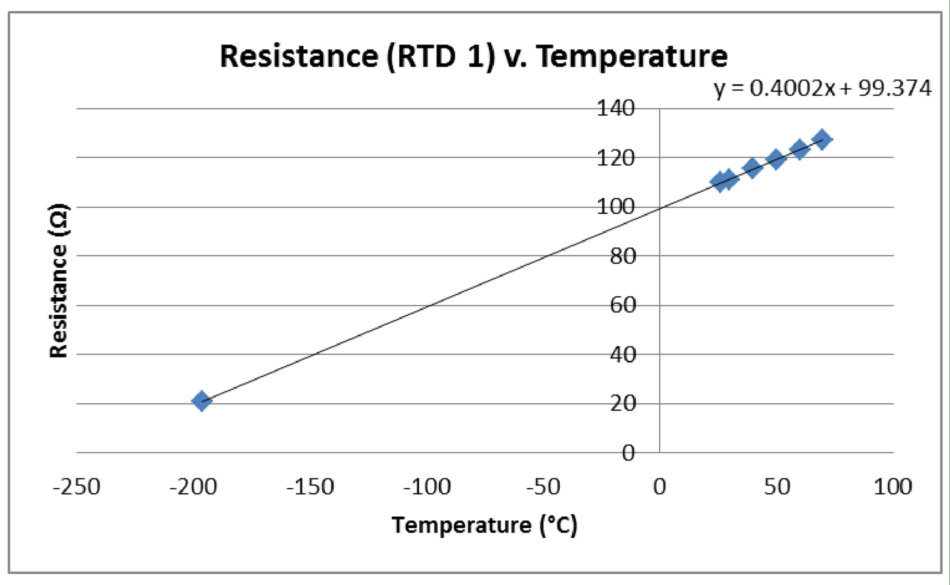
The LAPD will primarily look at cosmic ray muons as a way to achieve this goal. Cosmic radiation is primarily composed of high energy protons, alpha particles, and heavier nuclei which are believed to originate from super novae and quasars across the universe. These particles, however, do not reach Earth’s surface. Upon entering the atmosphere these particles interact via the strong force with the nitrogen and oxygen molecules in the atmosphere, producing charged pions. Pions have an average lifetime of 26 ns at rest, and even when taking relativistic effects into account the pions will only travel about 760 m before decaying into muons. The muons can be detected and measured at ground level because they do not interact via the strong force[1]. Therefore, the muons provide the LAPD with an abundant source of charged particles to detect and measure.

Model TPC

The TPC is roughly 2 m in height and sits at the center of the liquid argon tank. The TPC is fragile, so a model TPC was created for practicing insertion. The model was made from two concrete tube forms, approximately 30.5 cm in diameter. The electronics at the top of the TPC are simulated by foam blocks, covered with a sheet of plastic. Ribbon wire was used to simulate the cabling needed for the wire plane, and PVC piping provided the clamps which hold the cabling in place.

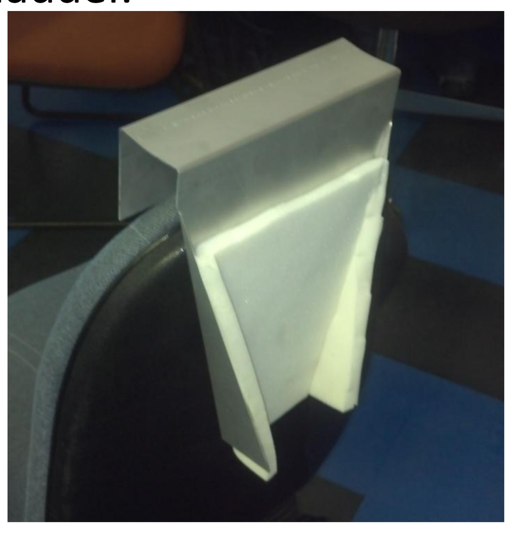
Temperature Monitoring

Resistance temperature detectors (RTD’s) will be placed in various locations around the tank to monitor temperature gradients in the liquid argon. Three RTD’s will be mounted on a circuit board and monitored while in the tank. Below is a graph which shows one RTD measured at different temperatures. The resistance varies linearly as the temperature changes, therefore the temperature at any resistance can be inferred. While being monitored, the temperature of the RTD will raise slightly due to the electrical resistance. The heating due to electrical resistance can be predicted using the thermal mass and the heat input. Using the equations $P=I^2R$ and $Q=C_{TH}\Delta T$ the power input, heat input, and thermal mass was calculated, resulting in an expected temperature change of .001273 °C/s.



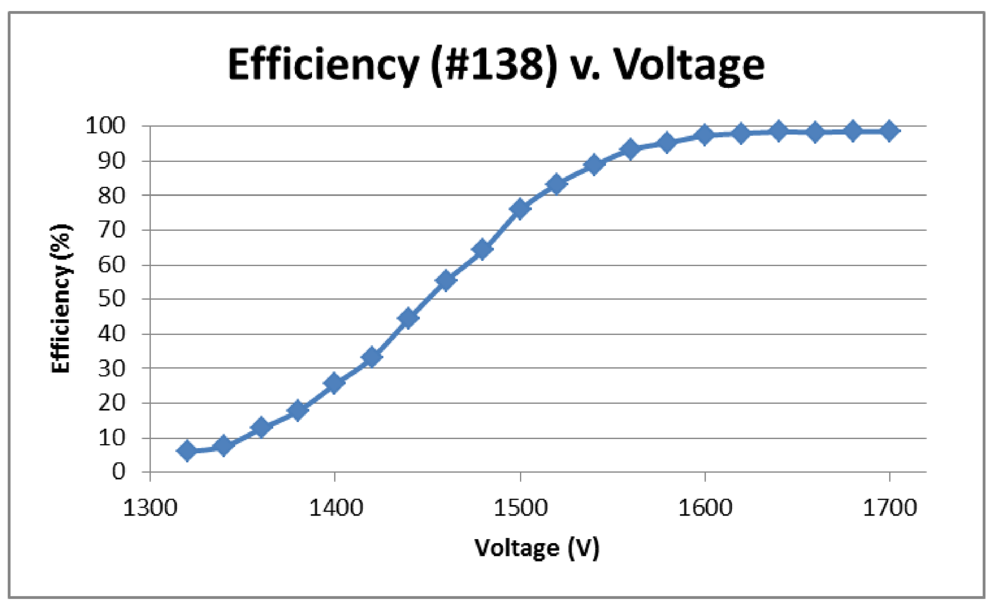
LAPD Tank and Setup

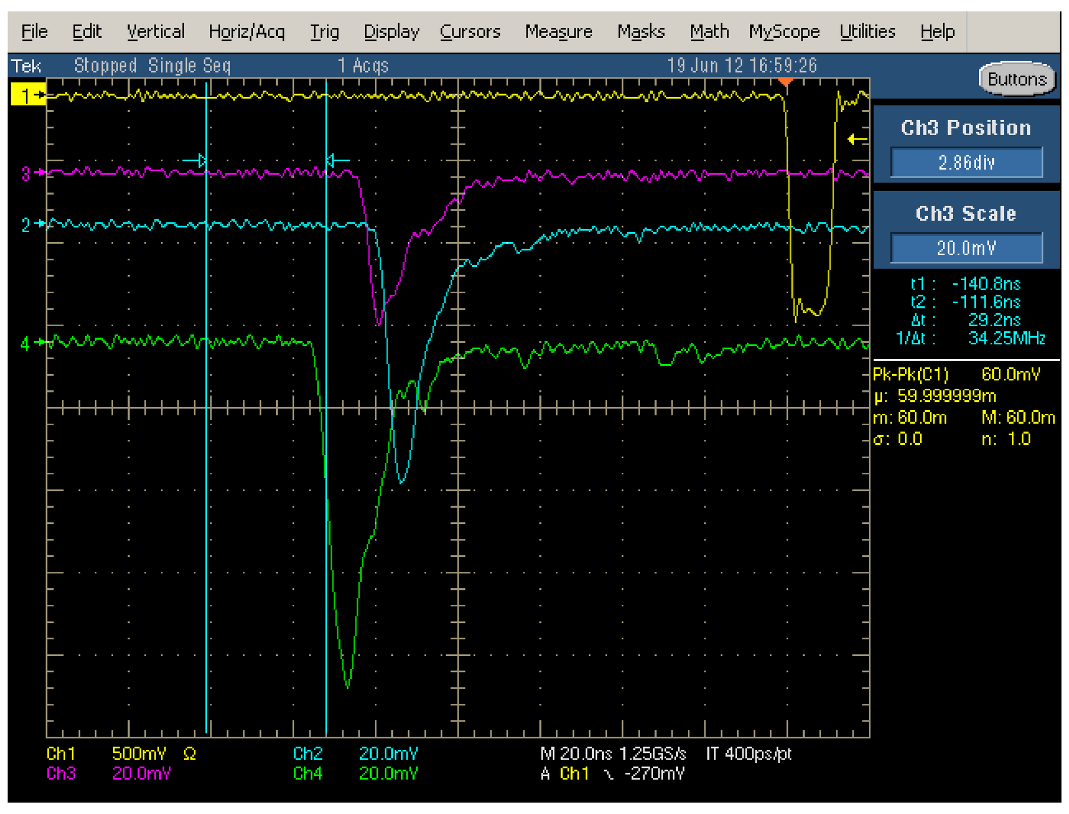
The LAPD tank (shown to the right) has a volume of approximately 22 240 L, Has a diameter and height of about 3.1 m, and has the capacity to hold 28 123 kg of liquid argon. The tank is insulated using a combination of fiberglass and foam. The scintillators are placed every 60° around the tank. Three scintillators are hung on externally mounted ladders (shown below). The top two scintillators are wired together using a coincidence module, and thus act as one large scintillator. These two scintillators are then wired together with the lowest scintillator on the ladder directly across from it. This provides the greatest angle of possible coincidence through the TPC. Aluminum holders were fabricated to hang the scintillators from the ladder. Pictured below are the holders used to hang the scintillators on the ladder.



Scintillators and Efficiencies

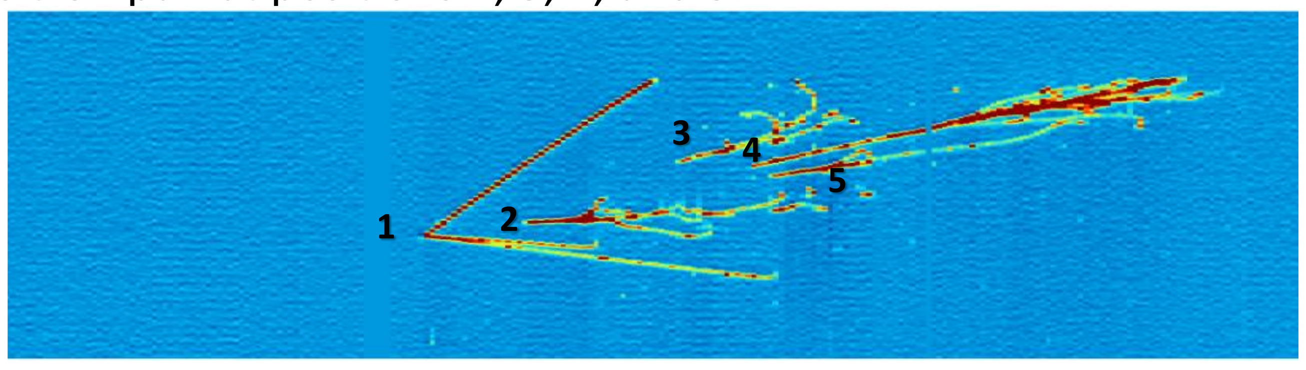
When a muon passes through a piece of scintillating material, it excites an electron from its ground state. Upon returning to its ground state, it will release a photon. The energy and wavelength of this photon is determined via the Stokes Shift. The Stokes Shift says that an emitted photon will have less energy (and thus a longer wavelength) than the energy it was excited with [2]. This is what allows the scintillators to work. If the emitted photon did not have less energy it would simply be re-absorbed and not travel through the plastic. When the photon reaches the end of the plastic, it is guided to a photomultiplier tube (PMT), where the photon induces a cascade of electrons. These electrons can then be read as an electrical signal. Each PMT is different, so the efficiency of each counter was tested. The tests were performed by stacking three scintillators on top of one another. The efficiency of the middle scintillator was calculated by dividing the coincidences of all three scintillators by the number of coincidences between the two outside scintillators. The oscilloscope output to the right shows a coincidence between three counters: channel one is the coincidence, and channels 2, 3, and 4 shows the output of the three counters. If the counters aren’t efficient, some muons may not be detected, so it is important each PMT is set at the correct operating voltage.





Neutrino Interactions in LAr

The LBNE will look at neutrino interactions in an attempt to understand their oscillations. The picture below shows a sample of data the LBNE would be able to produce. A muon neutrino interacts with a neutron at position 1, producing a muon, proton, two neutral pions, and a positive pion. This can be represented by the following interaction: $\nu_\mu + p \rightarrow \mu^- + p + 2\pi^0 + \pi^+$. The two neutral pions decay almost instantaneously into four high-energy photons. These photons then interact with an argon atom, producing an electron-positron pair at positions 2, 3, 4, and 5.



References and Acknowledgements

[1] P.K.F. Greider, “Cosmic Ray Properties, Relations and Definitions,” in *Cosmic Rays at Earth*, 1st ed. Amsterdam, The Netherlands: Elsevier Science B.V., 2001, ch. 1, pp. 2-5.

[2] M. Longair, “Einstein and the Quantisation of Light,” in *Theoretical Concepts in Physics*, 2nd ed. Cambridge, United Kingdom: The Press Syndicate of the University of Cambridge, 2003, ch. 14, pp. 353.

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